Section 3: Overview of the PJM Regulation Market

Welcome to the Overview of the PJM Regulation Market section of the PJM Manual for Energy & Ancillary Services Market Operations. In this section you will find the following information:

- An overview description of the PJM Regulation Market (see "Overview of PJM Regulation Market").
- A list of the PJM Regulation Market Business Rules (see "PJM Regulation Market Business Rules").

3.1 Overview of the PJM Regulation Market

The PJM Regulation Market provides PJM participants with a market-based system for the purchase and sale of the Regulation ancillary service. Resource owners submit specific offers for Regulation Capability and Regulation Performance, and PJM utilizes these offers together with energy offers and resource schedules from the eMKT System, as input data to the Ancillary Service Optimizer (ASO) which is an hour-ahead Market Clearing Engine. Market Clearing Engine (MCE). ASOMCE then optimizes the RTO dispatch profile and forecasts LMPs to determine hourly commitments of Regulation to meet the requirement. In real-time PJM jointly optimize the Regulation committed simultaneously with energy and reserve and calculate an hourly Regulation Market Clearing Price (RMCP) and , Regulation Market Performance Clearing Price (RMPCP), which are used to derive the Regulation Market Capability Clearing Price (RMCCP) every 5 minutes based on the current system conditions. All 5 minutes, real-time, Regulation prices will be averaged to calculate the hourly Regulation Market Performance Clearing Price (RMPCP) and Regulation Market Capability Clearing Price (RMCCP). These clearing prices are then used in market settlement to determine the credits awarded to providers and charges allocated to purchasers of the Regulation service.

PJM uses resource schedules, regulation, and energy offers from the eMKT System as input data to the ASOMCE to provide the lowest cost alternative for the procurement of Ancillary ServicesRegulation and energy for each hour of the operating day. The lowest cost alternative for thisese services is achieved through a simultaneous co-optimization of Regulation,with Synchronized Reserve, and energy. Within the co-optimization, an RTO dispatch profile is forecasted along with LMPs for the market hour and adjacent hours. Using the dispatch profile and forecasted LMPs, an opportunity cost, adjusted by applicable performance score and benefits factor, is estimated for each resource that is eligible to provide regulation. The estimated opportunity cost for demand resources will be zero. The estimated opportunity cost is then added to the adjusted total regulation offer price to create the merit order price. All available regulating resources are then ranked in ascending order of their merit order prices, and the lowest cost set of resources necessary to simultaneously meet the PJM Regulation Requirement, PJM Synchronized Reserve Requirement, and provide energy in that hour is determined and committed. Prices for Regulation will be

calculated simultaneously with energy and reserve every 5 minutes for the 12 intervals of the hour by Locational Pricing Calculator (LPC). The highest merit order price associated with this lowest cost set of resources awarded regulation becomes the RMCP. The RMPCP is calculated as the highest adjusted performance offer from the set of cleared resources. The RMCCP is the difference between RMCP and RMPCP. for that hour of the operating day, which will be used to set the RMPCP and RMCCP. Resource owners may self-schedule Regulation on any qualified resource, and the merit order price for any self-scheduled Regulation resource is set to zero.

In the after-the-fact settlement, any resources self-scheduled to provide Regulation are compensated based on the processes described in Manual 28.

3.2 PJM Regulation Market Business Rules

3.2.1 Regulation Market Eligibility

Regulation offers may be submitted only for those resources electrically within the PJM RTO.

To regulate, a resource must meet the following criteria:

- Generation resources must be able to provide 0.1 MW of Regulation Capability in order to participate in the Regulation Market. Demand Resources must be able to provide 0.1 MW of Regulation Capability in order to participate in the Regulation Market.

- Generation resources must have a governor capable of AGC control.

- Resources must be able to receive an AGC signal. Resources MW output must be telemetered to the PJM control center in a manner determined to be acceptable by PJM.

- New resources must pass an initial performance tests (minimum 75% compliance required). Current resources that are qualified on the date of implementation of regulation market changes do not need to re-qualify for the signal that they currently follow. However, initial qualification does not preclude a resource from being disqualified from the regulation market for non-performance.

- Resources must demonstrate minimum performance standards, as set forth in the PJM Manual 12: Balancing Operations, Section 4: Providing Ancillary Services.

- Resources should give priority to the regulation signal by not allowing the sum of the regulating ramp rate and energy ramp rate to exceed the economic ramp rate. Only after a regulating resource has accounted for the regulation capability, may a generator use net of the economic base point and the regulation ramp rate to follow the energy signal.

- Demand Resources must complete initial and continuing training on Regulation and Synchronized Reserve Market as documented in Manual 40: Certification and

Training Requirements, Section 2.6: Training Requirements for Demand Response Resources Supplying Regulation and Synchronized Reserve.

- Effective 6/1/2015: When a Demand Resource that is eligible for the Regulation Market is called for a mandatory Emergency or Pre-Emergency Load Management Event, it will be de-assigned from Regulation for any intervals that overlap with the Load Management Event, starting from the notice time of the Load Management Event, unless otherwise approved by PJM. PJM will not assign the resource to Regulation for the remainder of the mandatory portion of the Load Management Event.

The following information must be supplied through the eMKT System:

- Resource Regulating Status (available, unavailable, self-scheduled)
- Regulation Capability (above and below regulation midpoint, MW)
- Regulation Maximum and Minimum values, considering any necessary offsets (MW)
- Regulation Signal Type – RegA or RegD
- Cost-Based Regulation Offer ($/MWh): This value will be validated using the unit-specific operating parameters submitted with the regulation offer and the applicable $12/MWh regulation margin adder. The portions of the cost based offer are split into:
  - Regulation Capability portion capturing the Fuel Cost Increase and Unit Specific Heat Rate Degradation due to Operating at Lower Loads. The margin adder may only be added to the Regulation Capability portion; and,
  - Regulation Performance portion representing Cost Increase due to Heat Rate Increase during non-steady state operation and Cost Increase in VOM.
    - The $/MW value determined in this step will be converted to $/ΔMW by dividing the value by mileage ΔMW/MW for the applicable signal for that offer.
- Price-Based Regulation Offer ($/MWh, optional): This value is capped at $100/MWh, and its submission is optional on the part of the market participant. The portions of the cost based offer are split into:
  - Regulation Capability portion the capturing the resource owner's price to reserve MWs for regulation in $/MW; and,
  - Regulation Performance portion capturing the resource owner's price to provide regulation movement in $/ΔMW.

The $/MW value determined in this step will be converted to $/ΔMW by dividing the value by mileage ΔMW/MW for the applicable signal for that offer. In addition to the cost-based regulation offer price, each market participant may also submit additional information to support the cost-based offer price. Using the calculations in Manual M-15: Cost Development Guidelines, PJM will validate the cost-based regulation offer price to ensure that it does not exceed actual regulating cost as determined by this manual, plus the

applicable regulation margin adder. Any cost-based offer prices that exceed this value will be rejected by the eMKT System. An example of this calculation is available on the PJM website at http://www.pjm.com/markets-and-operations/ancillary-services.aspx.

If a market participant does not submit a cost-based regulation offer price they will not be permitted to participate in the PJM Regulation Market until such offer has been validated. Any participants that do not submit any of the supporting parameters below will have their cost-based regulation offer price capped at the margin adder of $12/MWh.

The following optional parameters may be submitted in the eMKT System to support the cost-based regulation offer price. If any of these parameters are not submitted they will default to zero.

- **Heat Rate @ EcoMax [BTU/kWh]:** The heat rate at the default economic maximum for a resource. The economic maximum that will correspond to this rate value will be the default economic maximum that is shown on both the Daily Regulation Offers and Unit Details pages.

- **Heat Rate @ RegMin [BTU/kWh]:** The heat rate at the default regulation minimum for a resource. The regulation minimum that will correspond to this rate value will be the default regulation minimum that is shown on both the Daily Regulation Offers and Unit Details pages**.**

- **VOM Rate [$/MWh of Regulation]:** The increase in VOM resulting from operating the regulating resource at a higher heat rate than is otherwise economic for the purpose of providing regulation.

- **Fuel Cost [$/MBTU]:** The fixed fuel costs of the resource. This value will be used to determine the heat rate adjustments during steady-state and non steady-state operation for the purpose of providing regulation.

3.2.2 Regulation Market Data Timeline

Cost-based and Price-Based Regulation Offer(s) and any applicable cost information must be supplied prior to 6:00 p.m. day-ahead and is applicable for the entire 24-hour period for which it is submitted. Resource Regulating Status, Regulation Capability, and Regulation Maximum and Regulation Minimum information may be submitted or changed up until sixty (60) minutes prior to the beginning of the operating hour, at which time the Regulation market closes. In the event that the Regulation Maximum and Regulation Minimum limits are not the most restrictive for a given resource (i.e. the Regulation Maximum the lowest of all the high limits and the Regulation Minimum the highest of all the low limits), the regulation software will utilize the most restrictive minimum and maximum of all applicable limits for real time.

- Should a unit wish not to participate in the regulation market in any given hour on the operating day, the following update should be made at least 60 minutes prior to the operating hour in the Regulation Updates screens of the eMKT System:
    - Set Offer MW to zero

- o Set Available status to Not Available.

- Should a unit's regulation operating parameters change after the regulation market closes for an hour, the following changes may be made through direct communication with the PJM Scheduling Coordinator:

  - o Resource Regulating Status

  - o Available to unavailable

  - o Self-scheduled to unavailable

- High Regulation Limit may be decreased but not increased and Low Regulation Limit may be increased but not decreased.

- Regulating capability may be decreased but not increased.

- Regulation Maximum capability may be decreased but not increased and Regulation Minimum capability may be increased but not decreased.

- Any resource that is unavailable for energy when the Regulation market closes and becomes available during the operating hour may also be made available or self-scheduled for regulation. Any associated regulation offer information may be changed for such resources, since none was considered in the calculation of RMCP.

- Resources that are self-scheduled for energy but do not have an available bandwidth above the self-scheduled value and below the applicable maximum greater than or equal to twice the regulation offer cannot be evaluated for the full amount of the offer. Such resources will be evaluated for regulating capability equal to half the bandwidth available.

3.2.3 Regulation Bilateral Transactions

- Bilateral regulation transactions may be reported to PJM. Such reported bilateral regulation transactions must be for the physical transfer of regulation and must be reported by the buyer and subsequently confirmed by the seller through the eMKT System no later than 1600 the day after the transaction starts. Bilateral transactions that have been reported and confirmed may not be changed; they must be deleted and re-reported. Deletion of a reported bilateral transaction is interpreted as a change in the end time of the transaction to the current hour, unless the transaction has not yet started.

- The buyer on the transaction submits the MW amount, the seller, and the start and end time of the transaction via the eMKT System. The seller confirms the transaction via the eMKT System by 1600 the day after the start date of the bilateral transaction.

- Payments and related charges associated with the bilateral regulation transactions reported to PJM shall be arranged between the parties to the bilateral contract.

- A buyer under a bilateral regulation contract reported to PJM agrees that it guarantees and indemnifies PJM, PJM Settlement, and the market participants for the costs of any purchases by the seller in the Regulation Market, as determined by PJM, to supply the reported bilateral transaction and for which payment is not made to PJM Settlement by the seller.

- Upon any default in obligations to PJM or PJM Settlement by a Market Participant, PJM shall not accept any new bilateral reporting by the Market Participant and shall terminate all of the market participant's reporting of eMKT schedules associated with its bilateral regulation transactions previously reported to PJM for all days where delivery had not yet occurred.

3.2.4 Regulation Requirement Determination

- The total PJM Regulation Requirement for the PJM RTO is determined in whole MW for the on-peak (0500 – 2359) and off-peak (0000 – 0459) periods of day. Further detail can be found in Manual 12, Section 4.4.3 Determining Regulation Assignment.
- Demand Resources will be limited to providing 25% of the regulation requirement.

3.2.5 Regulation Obligation Fulfillment

- LSEs may fulfill their regulation obligations by:
- Self-scheduling the entity's own resources;
- Entering contractual arrangements with other market participants; or
- Purchasing regulation from the regulation market.

3.2.6 Regulation Offer Period

- Resource owners wishing to sell regulation service must at least supply a cost-based regulation offer reflecting both Regulation capability offer cost and the Regulation performance cost of the resource by 6:00 p.m. the day prior to operation, and the remainder of the necessary data prior to Regulation market closing as stated above in the Regulation Market Date Timeline section.
- Regulation offers are locked as of 6:00 p.m. the day prior to operation. The Markets Database is generally unavailable for entry between 12 noon and 4:00 p.m. the day prior to operation while the Day-ahead market is being cleared. All resources listed as available for regulation with no offer price have their offer prices set to zero.

3.2.7 Regulation Market Clearing

- PJM clears the regulation market simultaneously with the synchronized reserve market, and posts the results no later than 30 minutes prior to the start of the operating hour.

Dispatch

- Economic ramp rate must be adjusted when resources provide regulation to minimize the conflict between energy and regulation products. The segment specific ramp rates should be calculated from the economic ramp rate as follows:

$$Reduced\ Energy\ Ramp\ Rate = \max\left(0, Economic\ Ramp\ Rate - \frac{Cleared\ Regulation\ Capacity\ (AREG)}{5\ Minutes}\right)$$

- To increase consistency in the Individual Generator Dispatch (IGD) set point sent by PJM while a unit is regulating, the IGD set point will only move up when the RT-SCED LMP justifies raising the resource and resource's net MW output is near or above the current set point. The IGD set point will only move down when the RT-SCED LMP justifies lowering the resource and the resource's net MW output is near or below the current set point. The minimum ramp rate is a member-entered, unit-specific percentage of the bid-in ramp rate for each resource. If no value is entered for the resource, a default of zero will be used.

- A small dead band will be used to determine if the resource's MW output is near the current set point. The settings for this dead band will be the greater of 5 percent of the current net MW for the resource or 5 MW.

Regulating Capability

- For each resource, PJM will calculate an adjusted Capability Cost, as

$$Adjusted\ Regulating\ Capability\ Cost\ (\$) = \frac{\left(Offer\left(\frac{\$}{MW}\right)\right)}{\left(\begin{array}{c}Benefits\ Factor\\of\\Offered\ Resource\end{array}\right)} * \frac{\left(\begin{array}{c}Capability\\(MW)\end{array}\right)}{\left(\begin{array}{c}Historic\\Performance\\Score\end{array}\right)}$$

- By dividing the regulating capability offer by benefits factor of the specific offered resource and the historic performance score. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource.

Mileage and the Performance Offer

- Mileage is the summation of movement requested by the regulation control signal a resource is following. It is calculated for the duration of the market hour for each regulation control signal (i.e. RegA and RegD).

$$Mileage_{RegA} = \sum_{i=0}^{n} |RegA_i - RegA_{i-1}|$$

$$Mileage_{RegD} = \sum_{i=0}^{n} |RegD_i - RegD_{i-1}|$$

- PJM calculates the performance-adjusted Performance Cost, as

$Adjusted\ Performance\ Cost\ (\$)$

$$= \frac{\left(\begin{array}{c} Performance \\ Offer\ (\$/\Delta MW) \end{array}\right) * \left(\begin{array}{c} Mileage \\ of \\ Offered\ Resource \\ Signal\ Type\ (\Delta MW/MW) \end{array}\right)}{\left(\begin{array}{c} Benefits\ Factor \\ of \\ Offered\ Resource \end{array}\right) * \left(\begin{array}{c} Historic \\ Performance \\ Score \end{array}\right)} * \left(\begin{array}{c} Capability \\ (MW) \end{array}\right)$$

- Similar to the Adjusted Regulating Capability Offer, the Adjusted Performance Offer is adjusted by the benefits factor of the specific offered resource and the historic performance score of the resource. Benefits factor is discussed later in this section. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource. The performance offer is priced on a $ per change in MW, to normalize the performance between signal types, the historical mileage is a rolling 30-day average by the signal type that the resource has qualified to follow.

- Lost Opportunity Cost

- Estimated resource opportunity cost is calculated as follows:

  - The Market Clearing Engine (MCE) optimizes resource energy schedules and forecasts LMPs for the operating hour while respecting appropriate transmission constraints and Ancillary Service requirements.

  - MCE utilizes the lesser of the available price-based energy schedule or most expensive available cost-based energy schedule (the "lost opportunity cost energy schedule"), and forecasted LMPs to determine the estimated opportunity cost each resource would incur if it adjusted its output as necessary to provide its full amount of regulation.

- Regulation opportunity cost is divided into three components.

  - The lost opportunity cost incurred in the shoulder hour preceding the initial regulating hour while the unit moves uneconomically into its regulating band to comply with the next hour's regulation assignment.

  - The lost opportunity cost incurred in the actual regulating hour from reducing or raising the unit's output uneconomically for the purpose of providing regulation.

  - The lost opportunity cost incurred in the shoulder hour following the final hour of the regulation assignment while the unit moves from its uneconomic regulation set point back to its economic set point.

- The approximate formula for the lost opportunity incurred during the shoulder hours can be defined as:

  $|LMP_{SH} - ED| * GENOFF * TIME$, where:

    a. LMP_{SH} is the forecasted shoulder hour LMP at the generator bus,

    b.   ED is the price from the lost opportunity cost energy schedule associated with the setpoint the resource must maintain to provide its full amount of regulation, and

    c.   GENOFF is the MW deviation between economic dispatch and the regulation setpoint.

    d.   TIME is the percentage of the hour it would take the unit to reduce GENOFF MWs using the applicable offer-in ramp rate.

- The approximate formula for the lost opportunity cost incurred during the regulating hour is:

$$|LMP - ED| * GENOFF, \text{ where:}$$

    e.   LMP is the forecasted hourly LMP at the generator bus,

    f.   ED is the price from the lost opportunity cost energy schedule associated with the setpoint the resource must maintain to provide its full amount of regulation, and

    g.   GENOFF is the MW deviation between economic dispatch and the regulation setpoint.

- All unit-specific lost opportunity costs will be divided by the benefits factor of the specific offered resource and the resource's historic performance score for the purposes of commitment and setting the regulation market clearing prices. Benefits factor is discussed later in this section. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource.

$$Adjusted\ Lost\ Opportunity\ Cost\ (\$) = \frac{\left(\begin{array}{c}Estimated\ Lost\ Opportunity \\ \left(\frac{\$}{MW}\right)\end{array}\right)}{\left(\begin{array}{c}Benefits\ Factor \\ of \\ Offered\ Resource\end{array}\right)} * \frac{\left(\begin{array}{c}Capability \\ (MW)\end{array}\right)}{\left(\begin{array}{c}Historic \\ Performance \\ Score\end{array}\right)}$$

- Both lost opportunity cost calculations are defined simplistically for the purpose of the manual. The actual calculations are integrations that may be visualized as the area on a graph enclosed by the lost opportunity cost energy schedule, the points on that curve corresponding to the resource's desired economic dispatch and the setpoint necessary to provide the full amount of regulation, and the LMP.

- PJM may call on resources not otherwise assigned in order to provide regulation, in accordance with PJM's obligation to minimize the total cost of energy, operating

reserves, regulation, and other ancillary services. If a resource is called on by PJM for the purpose of providing regulation, the resource is eligible for recovery of Regulation lost opportunity costs as well as start-up, no-load, and energy costs. Please refer to Manual 28: Operating Agreement Accounting for additional settlements details.

- Resources not eligible or with no lost opportunity associated with providing regulation:

  o Energy resources that are self-scheduled to provide energy and do not supply an energy offer.

  o Demand Resources

- Notwithstanding the above, resources that do not submit an energy offer curve will have a Lost Opportunity Cost of zero.

Total Offer

- Each resource must be ranked based on the total expected cost of that resource regulating. PJM calculates the Adjusted Total Offer of the resource as follows:

$$Adjusted\ Total\ Offer\ Cost\ (\$) = \begin{pmatrix} Adjusted \\ Regulation \\ Capability \\ Cost \\ (\$) \end{pmatrix} + \begin{pmatrix} Adjusted \\ Lost \\ Opportunity \\ Cost \\ (\$) \end{pmatrix} + \begin{pmatrix} Adjusted \\ Performance \\ Cost \\ (\$) \end{pmatrix}$$

Regulation Market Clearing Prices
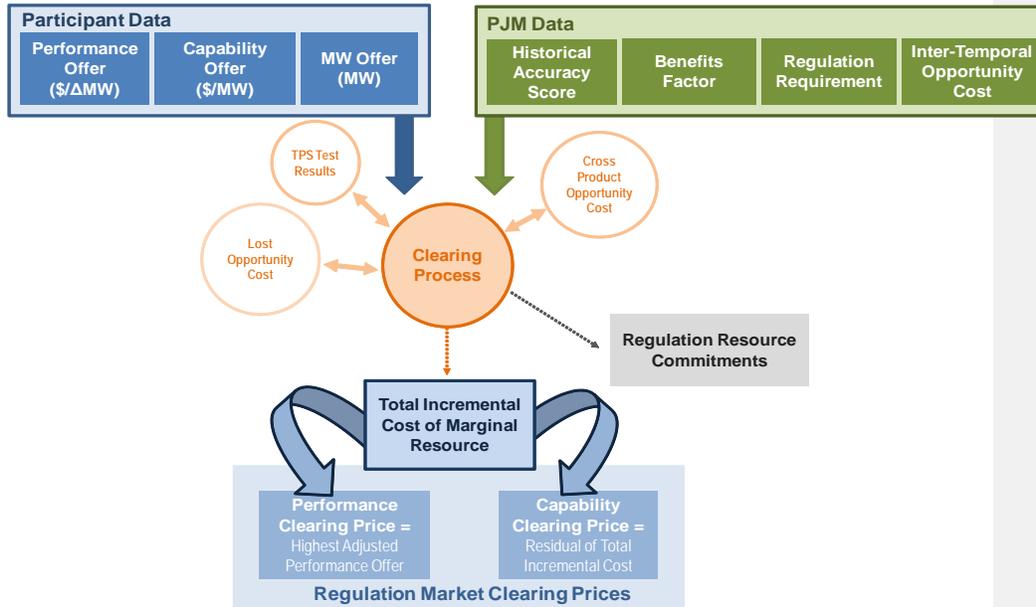
- MCE ranks all available regulating resources in ascending merit order price, and simultaneously determines the least expensive set of resources necessary to provide energy, regulation and synchronized reserve for the operating hour taking into account any resources self-scheduled to provide any of these services. The Rank price is determined as follows:

$$Rank\ Price = \frac{Adjusted\ Total\ Offer\ Cost\ (\$)}{Capability\ (MW)}$$

- Should the MCE application be unable to fulfill both the Regulation and Synchronized Reserve requirements, regulation receives the higher priority.

- PJM will clear the market to meet the Regulation Capability Requirement. The Regulation Capability Requirement sets the amount of regulating capability that PJM believes it would need to absorb sustained RTO ACE deviations adjusted by the benefits factor of a specific offered resource and the resource's historic performance score. Benefits factor is discussed later in this section. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource. The market will assign ~~units~~ resources until the constraint is met, by

$$Regulation\ Capability\ Requirement$$
$$MW$$
$$\leq \sum_{i=0}^{n} Capability\ (MW)_{i*} * Benefits\ Factor\ of\ Offered\ Resource_i$$
$$* Historic\ Performance\ Score_i$$

- With the Regulation Capability constraint satisfied, the Rank Price ($/MW) of the last assigned resource sets the Regulation Market Clearing Price (RMCP). This RMCP is used to derive the clearing price for the Regulation Capability and Regulation Performance components. First the Regulation Market Performance Clearing Price (RMPCP) is calculated by finding the maximum performance offer from the set of all cleared resources' performance offers as follows:

$$Regulation\ Market\ Performance$$
$$Clearing\ Price$$
$$\$/MW$$

$$= \max_{Assigned\ Resources} \left(\frac{\left(\begin{matrix} Performance \\ Offer \\ (\$/\Delta MW) \end{matrix} \right) * \left(\begin{matrix} Actual\ Mileage \\ of \\ Offered\ Resource\ Signal\ Type\ \Delta MW/MW \end{matrix} \right)}{\left(\begin{matrix} Benefits\ Factor \\ of \\ Offered\ Resource \end{matrix} \right) * \left(\begin{matrix} Historic \\ Performance \\ Score \end{matrix} \right)} \right)$$

- Then the RMPCP is subtracted from the RMCP for the Regulation Market Capability Clearing Price (RMCCP), which it the residual between the RMCP and RMPCP.

$$\begin{matrix} Regulation\ Market\ Capability \\ Clearing\ Price \\ \$/MW \end{matrix} = \left(\begin{matrix} Regulation\ Market \\ Clearing\ Price \\ \$/MW \end{matrix} \right) - \left(\begin{matrix} RM\ Performance \\ Clearing\ Price \\ \$/MW \end{matrix} \right)$$

- The five minute regulation clearing prices are posted in the eDATA user interface public view. RMCP(s) and other billing determinant information is also available on the PJM website at http://www.pjm.com/markets-and-operations/market-settlements/preliminary-billing-reports.aspx

- If no Regulation Market Results are posted to the eMKT MUI for an hour, PJM will continue the current assignments, as needed, into the un-posted hour. There will be no impact to the price calculation, the real time hourly integrated Regulation Clearing Prices will be used for settlement.
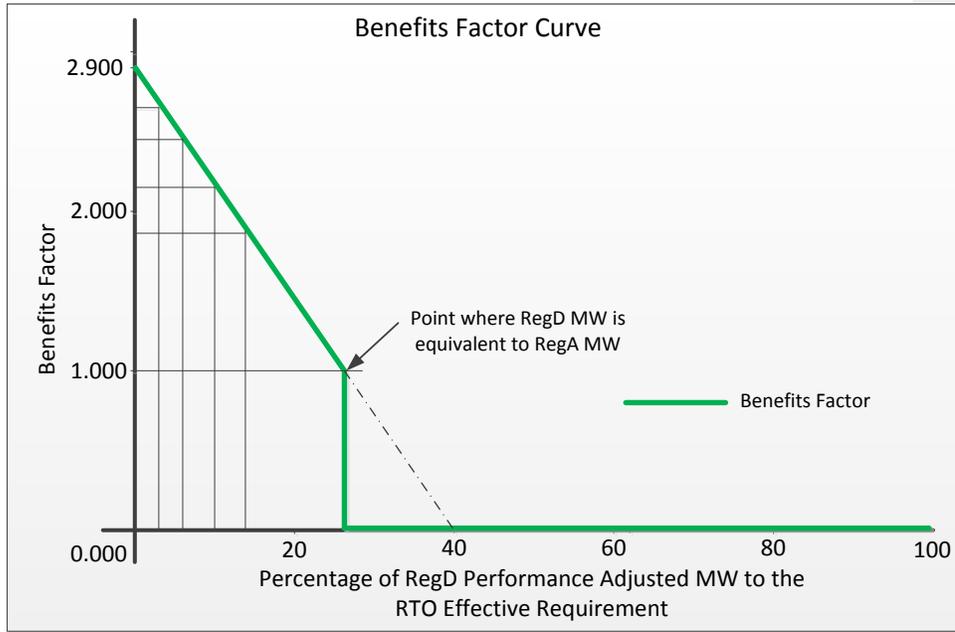
Benefits Factor Function

Regulating resources can follow either a RegA (traditional) or RegD (dynamic) signal based on their resources' limitation and business practices. The regulating resources cleared in any hour can be any set of or mix of both traditional and dynamic resources. There is an operational relationship between the regulating resource mix and how the regulation requirement is satisfied. This relationship is included in the market clearing ~~and settlement~~ ~~p~~process as the Benefits Factor Function because the relationship is depicted as a curve.

The benefits factor translates fast moving resource's MWs into traditional MWs or Effective MWs. These Effective MWs reflect the rate of substitution between resources following the different regulation signals. For market clearing, each dynamic resource will be assigned a decreasing and unique benefits factor. The benefits factor of the offered resource or resource specific benefits factor is the marginal point on the benefits factor function that aligns with the last MW adjusted by historical performance that specific resource will add to the dynamic resource stack.
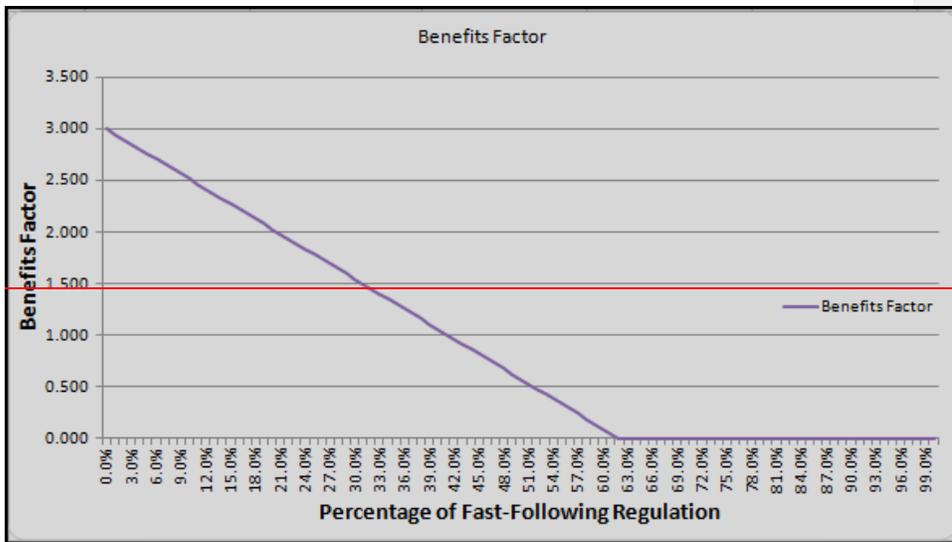
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Benefits Factor Curve

The benefits factor ranges from 2.9 to 10 where a benefits factor of 1 is equivalent to a traditional resource. The Benefits Factor Function will be fixed during the initial deployment. PJM will review the benefits factor as operational conditions warrant theto re-evaluate the relationship when needed. These operational conditions could include, among other factors, changes to the regulation signal tuning parameters, changes in the set of resources providing regulation service, and changes to the regulation requirement.

PJM determines the benefits factor based on the expected impact that fast-following resources have on the NERC reliability criteria. Determination of expected response will be based a combination of off-line models, analysis of the regulation signals, and the historical operational data as it accumulates. Historical operational data will be given increasing weight to the benefits factor determination over time. Changes to the benefits factor function will be made periodically after review at the Operating Committee.

The net impact of the use benefits factor is to increase in the likelihood of dynamic resources being selected in the clearing process, up to the point where RegD benefits is equivalent of that of RegA; that is, RegD benefits factor is equal to 1.of diminishing returns. RegD resource with a benefits factor less than 1 will not be considered in the regulation clearing for RegD because of its reduced benefits as depicted on the benefits factor curve.

Beyond the point of diminishing returns (1 to 0), the benefits factor will decrease the likelihood of fast-following resources getting clearing.

Benefits factor is calculated for each qualify RegD resources participating in the Regulation Market for each hour Regulation is clearing in ASO one hour ahead of real-time. Also, benefits factor is re-calculated for each RegD resources committed and providing regulation service in real-time for every 5 minutes of LPC intervals of the hour. Benefits factor of RegA resource is always 1.

Benefits factor calculation steps include:

- Step 1: Calculation of the Performance Adjusted MW

$$Performance\ Adjusted\ MW = Capability\ (MW) * Historical\ Performance\ Score$$

- Step 2: Calculation of the Initial Adjusted Total Offer Cost

$$Initial\ Adjusted\ Total\ Offer\ Cost\ (\$)$$

$$= \begin{pmatrix} Adjusted \\ Regulation \\ Capability \\ Cost \\ (\$) \end{pmatrix} + \begin{pmatrix} Adjusted \\ Lost \\ Opportunity \\ Cost \\ (\$) \end{pmatrix} + \begin{pmatrix} Adjusted \\ Performance \\ Cost \\ (\$) \end{pmatrix}$$

$$+ \left(\cfrac{1}{\begin{pmatrix} Benefits \\ Factor \\ of \\ Offered \\ Resource \end{pmatrix} * \begin{pmatrix} Historic \\ Performance \\ Score \end{pmatrix}} \right)$$

$$in\ this\ step, the\ resource\ benefits\ factor\ is\ assumed\ to\ be\ 1$$

- Step 3: Calculation of the rolling performance adjusted MW based on the initial adjusted total cost rank ascend.

- Step 4: Calculation of the resource specific benefits factor based on the defined benefits factor curve

  o Resource or group of resources (where the initial adjusted total offer cost is the same) is assigned benefits factor based on the initial adjusted total offer cost stack

  o The resource of group of resources benefits factor is the point on the benefits factor curve that aligns with the last megawatt,

adjusted by historical performance, that resource will add to the RegD stack

Three Pivotal Supplier Test

PJM utilizes the Three Pivotal Supplier (TPS) Test in the regulation market to mitigate market power as detailed in section 3.2.2A.1 of the PJM Tariff. Each supplier, from 1 to n, is ranked from the largest to the smallest offered MW of eligible regulation supply adjusted by the resource-specific benefits factor and the resource specific performance score in each hour. Suppliers are then tested in order, starting with the three largest suppliers. In each iteration of the test, the two largest suppliers adjusted by the benefits factor of offered resource and the resource specific performance score are combined with a third supplier adjusted by the benefits factor of offered resource and the resource specific performance score, and the resulting combined supply is subtracted from total effective supply adjusted by the benefits factor of offered resource and the resource specific performance score. The resulting net amount of eligible supply is divided by the regulation requirement for the hour adjusted by the resource-specific benefits factor and the resource specific performance score (D). Where j defines the supplier being tested in combination with the two largest suppliers (initially the third largest supplier with j=3). Equation 0-1 shows the formula for the residual supply index for three pivotal suppliers (RSI3):

$$RSI3_j = \frac{\sum_{i=1}^{n} S_i - \sum_{i=1}^{2} S_i - S_j}{D}.$$

Where j=3, if RSI3j is less than or equal to 1.0, then the three suppliers are jointly pivotal and the suppliers being tested fail the three pivotal supplier test. Iterations of the test continue until the combination of the two largest suppliers and a supplier j result in RSI3j greater than 1.0. When the result of this process is that RSI3j is greater than 1.0, the remaining suppliers pass the test. Any resource owner that fails the TPS Test will be offer-capped.

- Regulating resources are offer-capped at the lesser of their cost-based or market-based regulation offer price.
- An offer-capped resource will only be offer-capped for a single hour at a time as the TPS Test is rerun for each hour of the day.
- Resource merit order price ($/MWh) = Resource regulation offer + estimated resource opportunity cost per MWh of capability adjusted by the resource-specific benefits factor and the resource specific performance score.

3.2.8 Hydro Units

- Since hydro units operate on a schedule and do not have an energy bid, opportunity cost for these units is calculated as follows:

- During those hours when a hydro unit is in spill, the ED value is set to zero such that the opportunity cost is based on the full value of LMP. During the operating day, the operating company is responsible for communicating this condition to the PJM Scheduling Coordinator, and indicating this condition on the Regulation Updates page of the eMKT System.

- If a hydro unit is committed day-ahead with MW greater than zero, the formula is the same as Section 3.2.7.Regulation Market Clearing and Dispatch above, except the ED value is an average of the LMP at the hydro unit bus for the appropriate on-peak (0700 - 2259) or off-peak (0000 – 0659, 2300 - 2359) period, excluding those hours during which all available units at the hydro plant were operating. If this average LMP value is higher than the actual LMP at the generator bus, the opportunity cost is zero. Day-ahead LMPs are used for the purpose of estimating opportunity costs for hydro units, and actual LMPs are used in the lost opportunity costs for settlement.

- If a hydro unit is brought on out of schedule to provide regulation or not committed in day-ahead market with MWs greater than 0, the opportunity cost is equal to the average LMP (calculated as stated above) minus the actual LMP at the generator bus. If the actual LMP is higher than the average, the opportunity cost is zero.

- When determined to be economically beneficial, PJM maintains the authority to adjust hydro unit schedules for those units scheduled by the owner if the owner has also submitted a regulation offer for those units and made the units available for regulation.

- An example of Regulation Hydro Lost Opportunity Cost Calculations can be found on the PJM website at http://www.pjm.com/markets-and-operations/ancillary-services/mkt-based-regulation.aspx

3.2.9 Regulation Market Operations

- The PJM Operator maintains total Regulation Zonal capabilities within a +/- 2%, but no less than +/- 15MW bandwidth around the RTO Regulation Requirement.

  > **Comment [A1]:** This statement needs revision or delete

- The PJM Operator periodically evaluates the set of resources providing regulation, and makes any adjustments to regulation assignments deemed necessary and appropriate to minimize the overall cost of regulation.

- In the event of a regulation excess, the PJM dispatcher deselects resources beginning with the highest cost resource currently providing regulation and moving downward.

- In the event of a regulation deficiency, the PJM dispatcher selects resources to provide regulation beginning with the lowest cost resource currently not providing regulation and moving upward.

- The RMCP and therefore RMPCP and RMCCP may ~~does not~~ change based upon regulating resource adjustments made in real time. Any opportunity costs that exceed the RMCP are credited after the fact on a resource-specific basis.

- The PJM Energy Management System (EMS) will send a RTO based signal(s) to each Local Control Center (LCC), as well as signals to individual resources or plants as requested by the owner.

- The PJM Operator communicates any change in resource regulating assignments to individual Local Control Centers. Company total in-service regulating capabilities are then telemetered back to the PJM EMS via the PJM data link.

- Resource regulation assignment changes during transitions between on-peak and off-peak periods begin 30 minutes prior to the new period, and are completed no later than 30 minutes after the period begins.

- For a dual qualified regulation resource, should the assignment change within the operating hour, the resource will continue to be committed or re-committed on the regulation signal type that the resource was initially committed on.

3.2.10 Settlements

- Please refer to Manual 28: Operating Agreement Accounting, Section 4: Regulation Accounting for settlement details.

- Regulation settlement is a zero-sum calculation based on the regulation provided to the market by generation owners and purchased from the market by LSEs.

- A resource's regulation performance score for the hour or the portion of the hour it is regulating will determine the resource's eligibility for regulation credit and lost opportunity cost for that hour. A resource whose performance score for the hour or the portion of the hour is below 25% will forfeit regulation credit and Lost Opportunity for that hour.

- Opportunity cost is calculated as shown above in Section 3.2.7 Market Clearing and Dispatch using actual integrated LMPs as opposed to that which was forecasted. PJM then adjusts the opportunity cost calculated for each resource based on the actual hourly integrated value of the real-time PJM regulation signal to account for the fact that the resource may have been held above or below its regulation set point for greater than half the hour and also adjusted by the resource-specific benefits factor and the resource specific performance score.

- Energy resources that are self-scheduled to provide energy and do not supply an energy offer are not eligible to collect opportunity cost credits. These resources will receive credit equal to the RMPCP and RMCCP times the amount of regulation self-scheduled on or assigned to them adjusted by the mileage ratio between the requested mileage for the regulation dispatch signal assigned to the resource and the mileage for the traditional regulation signal and the resource's actual performance score for an hour.

- For market settlement, regulating resources are compensated with consideration toward the resource's Regulation performance, and where applicable, the mileage ratio between the requested mileage for the regulation dispatch signal assigned to the resource and the mileage for the traditional regulation signal.